Analysis of Coexisting GPON and NG-PON1 (10G-PON) Systems

Marija D. Mraković and Petar S. Matavulj

Abstract — **In this paper, the simulation model of coexisting GPON and NG-PON1 (10G-PON) systems is presented, which has been developed for the analysis of feasibility and implementation issues of this coexistence. The aim was to analyze the impact of the most important parameters of the components that are needed for new network elements, on the performance of these coexistent networks. On the basis of the results obtained, the optimal parameters of the new system components were defined.**

Keywords — **10 Gb/s, coexistence, GPON (Gigabit Passive Optical Networks), NG-PON (Next Generation PON).**

I. INTRODUCTION

ALTHOUGH it is considered that GPON systems can provide enough capacity for the next few years, the time will soon come when the current xPON networks will have to migrate to solutions with a higher bandwidth. However, this development must be achieved in such a way to ensure a gradual transition from the existing to new systems.

In accordance with the new development plan of next generation systems which has been established by FSAN (Full Service Access Network) consortium, NG-PON systems are divided into two categories - stages of development: NG-PON1 and NG-PON2. Systems of the first phase (NG-PON1) will have two main goals: a fourfold increase in data rate per user compared to the existing GPON systems, at least in the downstream direction, and the provision of coexistence with existing GPON networks on the same ODN (Optical Distribution Network), which ensures smooth upgrade by enabling individual transition of users from the existing to the new system when the need to do so arises, with no impact on other users. Within NG-PON1, new XG-PON systems are defined, with a downstream data rate of 10 Gb/s. At the beginning of 2010., the first ITU-T recommendations of the G.987 series that define these systems were officially issued [1]-[3].

The easiest way to add 10G-PON network to an existing GPON network, is by using new wavelengths to transmit signals of the new system in both directions. According to the ITU-T G.987 recommendation, the ranges defined for the 10G-PON signal transmission are 1260-1280 nm for upstream and 1575-1580 nm for downstream transmission. At the OLT (Optical Line Terminal) side, the two systems are combined using an optical "coexister" filter, which is called WDM1 in ITU-T G.984.5 and G.987.

Due to the requirement that coexistence must be realized on the same, existing, ODN without its alteration, the existing characteristics on which 10 Gb/s systems (during the realization of coexistence) will not be able to influence (elements and components of this ODN network) are accepted as something that is unchangeable. Therefore, the performances of these networks will depend on those parameters of the new elements that can be optimized, and therefore it is important to consider what are the parameters of these new elements that can affect their performance.

II. THE MODEL OF GPON SYSTEM

The simulation model that was developed for the analysis represents a class B+ GPON system (with a loss budget of max 28 dB) which utilizes a centralized splitter architecture and uses one splitter with 1:32 split ratio. Downstream transmission direction of the 2.5 Gb/s data stream was considered. According to the ITU-T G.984, in such a network, a physical reach of 20 km must be achieved [4]. The system performance was required to be BER<10^{-10} [5]. The simulation model can be presented through three sections, representing the OLT transmitter, ODN and ONT (Optical Network Terminal) receiver.

OLT transmitter is represented as a NRZ signal transmitter, and a data signal is defined in the form of PRBS (Pseudo-Random Bit Sequence) with 2.5 Gb/s bit rate. The model of the transmitter consists of PRBS generator, which generates a pseudo-random sequence of bits at 2.5 Gb/s, NRZ pulse generator, CW (continuous wave) laser at 1490 nm and Mach-Zehnder modulator [6]. The external modulation of the CW laser was applied.

ODN network was modeled using the simulation elements that represent optical fiber, passive optical splitter and two optical attenuators to simulate the equivalent loss due to all connector and splice connections on the optical link. The optical fiber element simulated the characteristics of the ITU-T G.652D SMF28e Corning Fiber, taking into account all relevant physical effects such as fiber attenuation (a specified value of the fiber attenuation - fiber loss coefficient - is used), dispersion (coefficient of dispersion was calculated using the specified values of zero dispersion wavelength and zero dispersion slope), polarization dispersion and the impact

M. D. Mraković, Telekom Srbija a. d., Bulevar kralja Aleksandra 84, 11000 Belgrade, Serbia (phone: 381-64-6514371, e-mail: marija@telekom.rs).

P. S. Matavulj, Faculty of Electrical Engineering, University of Belgrade, Bulevar kralja Aleksandra 73, 11000 Belgrade, Serbia (e-mail: matavulj@etf.rs).

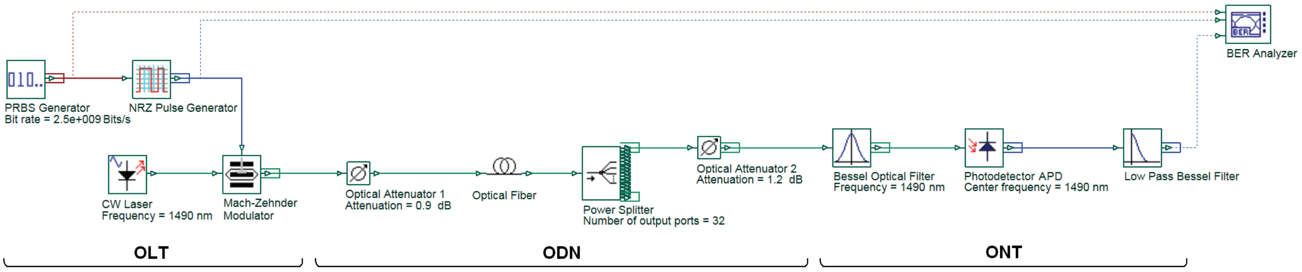


Fig. 1. The model of GPON system in downstream transmission direction (only one of 32 users is displayed), developed using OptiSystem simulation software [7].

of nonlinear effects. Since the architecture with a centralized splitter is simulated, one splitter with 1:32 split ratio was used for one fiber optic link. The insertion loss of this splitter was the same as of the commercially available splitters of the same splitting ratio – 17.5 dB. Because of the clarity of the picture, only one of 32 users of the simulated optical link is presented. In the analysis of the proposed network architecture in terms of equipment used for its realization, i.e. type and number of connections (splice or connector joint) that are needed, the exact amount of loss that these connections cause was calculated, and those values were used for adjusting the attenuator elements in the model. Attenuator 1 represents the loss of all connections from the OLT to the splitter, and attenuator 2 represents the loss of all connections from the splitter to the ONT.

The analysis of the influence of fiber link length on the signal propagation was performed by setting different values of the length of optical fiber parameter in an element that represents the feeder optical fiber. The proposed GPON network architecture assumes that the splitter is located close to all users that it serves, so distribution and drop sections of the cables are short, and attenuation of the signal during its propagation through them is negligible, so on these sections no simulators of the optical fiber were set. The more important losses on these sections are those due to the connector and splice connections, and their impact was taken into account using attenuator 2.

ONT receiver consists of an optical filter (which simulates the effect of diplexer that exists in the receiver), APD photodiode (photodetector) and electrical low pass filter. The diplexer effect that is simulated through the optical filter must have been taken into account, although upstream transmission was not considered in this model, because it exists in the receiver and the downstream signal passes through it.

Fig. 1 shows the proposed model of the GPON system described in this section. Measuring instrument elements were placed at certain points in this model, to enable observation of the performance of simulated system.

The values of the most important parameters of the used components are shown in Table 1.

Before adding a new 10G-PON system on such defined GPON system and analyzing their coexistence, the validity of the model must be determined by testing its performance in simulation and comparing the results with the requirements of ITU-T G.984.

TABLE 1: PARAMETERS OF THE GPON SYSTEM MODEL.

Component	***Parameter***	***Value***
PRBS generator	Bit rate	2.5 Gb/s
El. pulse generator	Line coding	NRZ
CW laser	DS wavelength	1490 nm
	Average Launched Power	1.5 – 5 dBm
	Linewidth	1 nm
Optical fibre	Fiber loss coefficient	0.25 dB/km
	Zero dispersion wavelength λ_0	1313 nm
	Zero Dispersion Slope S_0	0.086 ps/(nm^2·km)
Splitter	Insertion loss	17.5 dB
APD photodiode	Dark current	10 nA

III. GPON MODEL SIMULATION AND OBTAINED RESULTS

The two most important criteria of successful signal transmission in the GPON system are the propagation loss between OLT and ONT and BER.

During the simulation, this proposed model of the GPON system must achieve successful transmission over 20 km (as in the ITU-T G.984), with the transmitter output power in the range of 1.5 to 5 dBm, having BER $<10^{-10}$. The overall signal attenuation in the ODN must not be greater than 28 dB (class B+).

By measuring the transmitted and received signal optical power in the proposed GPON model it was calculated that a total loss during the optical signal propagation through the ODN was 27.65 dB and hence was in accordance with the maximum allowable attenuation for B+ class. The BER of $8.4 \cdot 10^{-11} < 10^{-10}$ was achieved. Based on these results, it was concluded that the proposed model can be accepted.

IV. ADDING A 10G-PON SYSTEM TO EXISTING GPON SYSTEM

A 10-GPON system is added on an existing GPON network using a WDM multiplexer. The elements of the 10G-PON transmitter and receiver are the same as for GPON, but with different parameter values. The values that differ are defined in ITU-T G.987.2 [3], and the whole range of recommended values was analyzed in simulation in order to define how these values affect system performance. The values are presented in Table 2, and the new coexistent system is shown in Fig. 2.

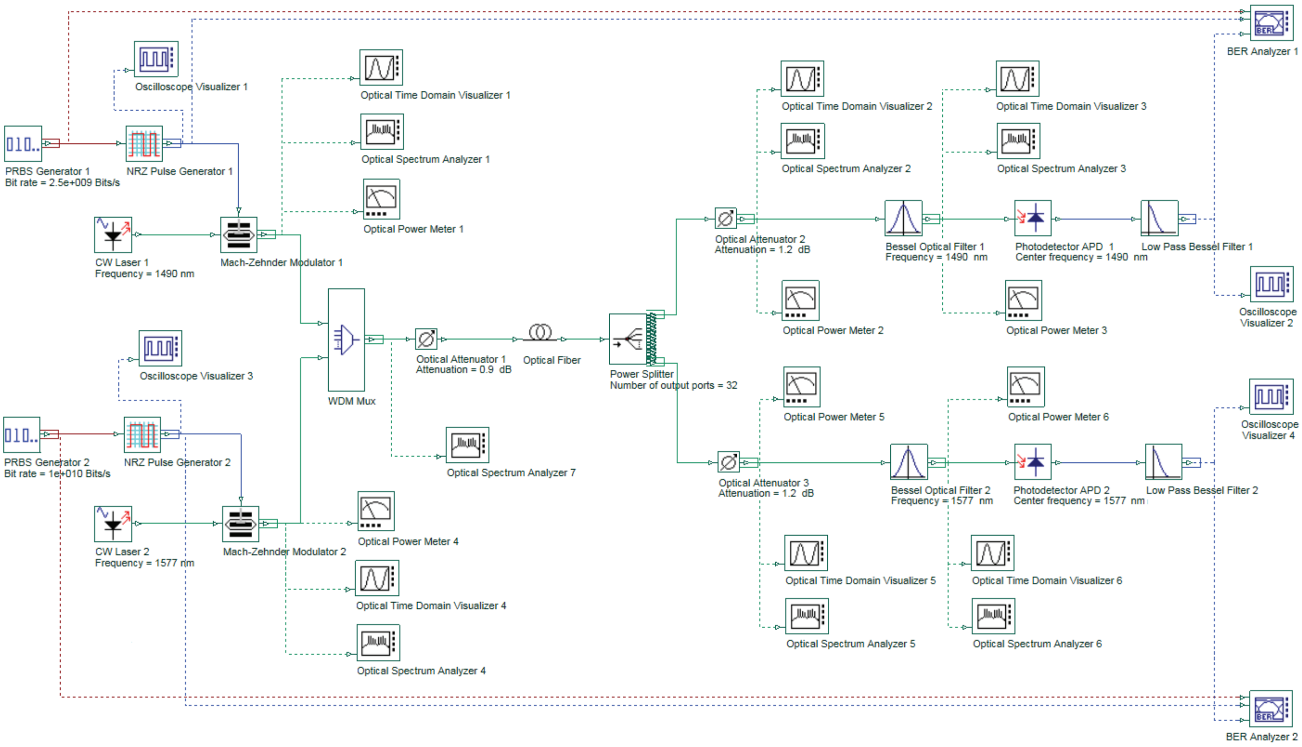


Fig. 2. The model of the coexistent GPON and 10G-PON systems in downstream transmission direction, developed using OptiSystem simulation software [7].

TABLE 2: PARAMETERS OF THE 10G-PON SYSTEM MODEL.

Component	***Parameter***	***Value***
PRBS generator	Bit rate	10 Gb/s
El. pulse generator	Line coding	NRZ
CW laser	DS wavelength	1577 nm
	Average Launched Power	2 - 6 dBm
Mach-Zehnder external modulator	Extinction ratio	> 8.2 dB
WDM1 MUX (filter characteristics)	Bandwidth	20 nm
	Depth	45 dB
	Insertion loss	0.7 dB

V. THE ANALYSIS OF COEXISTENT GPON AND 10G-PON SYSTEMS

After setting up a 10G-PON system associated with a GPON system, the first thing that had to be determined was whether the performances of the existing GPON system are impaired by the newly added 10G-PON. Analyzing BER of the GPON signal transmission in the most critical scenario with the value of the GPON OLT output power of 1.5 dBm (minimum allowed) and the value of the 10G-PON OLT output power of 6 dBm (maximum allowed), a slight degradation of BER was observed, comparing to the original system, but still the performances of the GPON system were retained in accordance with targeted: at a distance of 20 km BER was $9.2\cdot10^{-11}<10^{-10}$. Overall signal optical power loss through the ODN was measured 27.93 dB, which complies with class B+.

After these conclusions, the optimization of 10G-PON receiver was carried out, by adjusting the value of APD photodiode thermal noise. After defining a 10G-PON ONT in such way, the impact of the most important parameters of the new system's elements, such as output power and laser spectral width in the OLT transmitter, extinction ratio of the transmitted signal, and WDM1 filter bandwidth and depth was studied. As a result of this analysis, the minimum values of these parameters needed for a targeted system performance were defined, as well as their optimal values.

A. Optimization of the 10G-PON System

Before the optimization of the receiver, the overall attenuation for the 10G-PON signal in ODN network was measured, for a propagation distance of 20 km. It was important to determine whether the total loss of the new 10 Gb/s signal during its transmission from OLT to ONT will be in an acceptable range. Optical power of the signal was measured at the output of the 10G-PON OLT transmitter and at the input of the 10G-PON ONT receiver, for a link length of 20 km, as already mentioned, and the calculated overall loss was 28.35 dB. The power budget classes defined in new 10G-PON systems are Nominal1 (N1), with insertion loss maximum of 29 dB, and Nominal2 (N2), with insertion loss maximum of 31 dB [3]. Therefore, the new 10G-PON system can use optical components that belong to class N1.

After this analysis, the adjustment of 10G-PON ONT receiver sensitivity was performed, by observing the variation of BER with APD photodiode thermal noise values, and selecting an optimal value on the basis of the results obtained (Fig. 3). All parameter values were set as in Table 2, and simulation was performed for the minimum recommended transmitter output power of 2 dBm. As can be seen from the graphic, the maximum thermal noise which is allowed for APD photodiode, when using minimum output transmitter power, to maintain BER<10^{-10}, is $3.85 \cdot 10^{-24}$ W/Hz. It is important to underline that this is the maximum allowed value for the minimum output power of the OLT transmitter. But if this value can't be achieved during the realization of 10G-PON receiver (i.e. customer ONT equipment), or a less expensive receiver needs to be implemented, it can be realized with higher values of thermal noise, but in this case a higher output power of the OLT transmitter must be used.

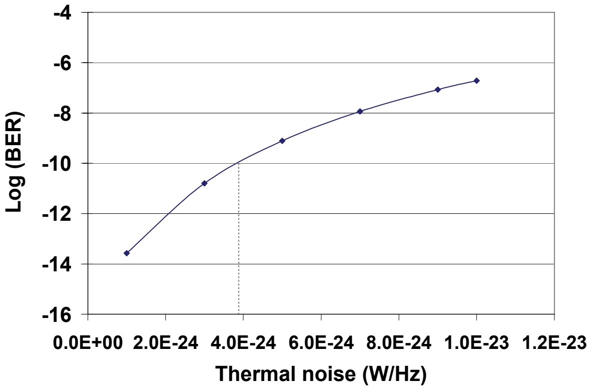


Fig. 3. Variation of BER with APD photodiode thermal noise in 10G-PON system, with P_{OLT}=2 dBm.

According to these results, the value of APD photodiode thermal noise of $3.5 \cdot 10^{-24}$ W/Hz was chosen for use in further simulation.

B. *Analysis of the Impact of Output Power of the 10G-PON OLT Transmitter*

The output power of the 10G-PON OLT transmitter is defined in the range of 2-6 dBm [3]. The variation of BER with the transmitter output power is depicted in Fig. 4. The analysis was performed for the optical link length of 20 km, which is the distance at which the system must achieve a satisfactory performance. It can be seen that after increasing the power by 4 dBm, a more than significant improvement in BER was achieved. The relative ratio of BER that is achieved at maximum and minimum transmitter output power was about 10^{11}.

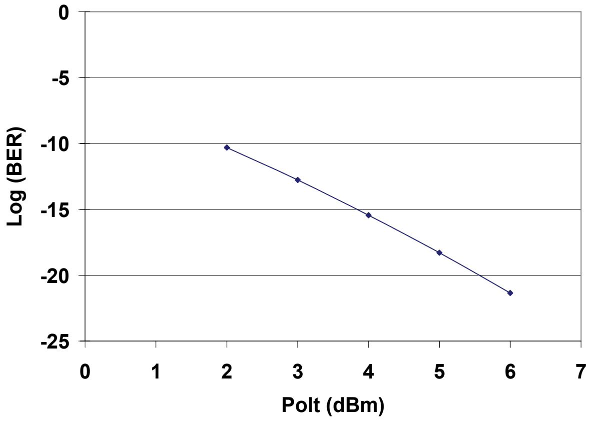


Fig. 4. Variation of BER with 10G-PON OLT transmit power at optical link length of 20km.

C. *Analysis of the Impact of 10G-PON OLT Laser Source Spectral Width*

It is interesting to examine to what extent the characteristics of light source affect system performance, and specifically the influence of the laser source spectral width. The impact was analyzed in the spectral width range of 0.1 - 1 nm, i.e. 12-120 MHz (for the 1577 nm wavelength). The results are shown in Fig. 5. According to graphic, it can be concluded that the spectral width has the affection on BER, but it is not very strong, especially for small changes in the spectral width. When increasing the spectral width from minimum to maximum tested values, i.e. 10 times (from 0.1 to 1 nm) BER deteriorates approximately 200 times.

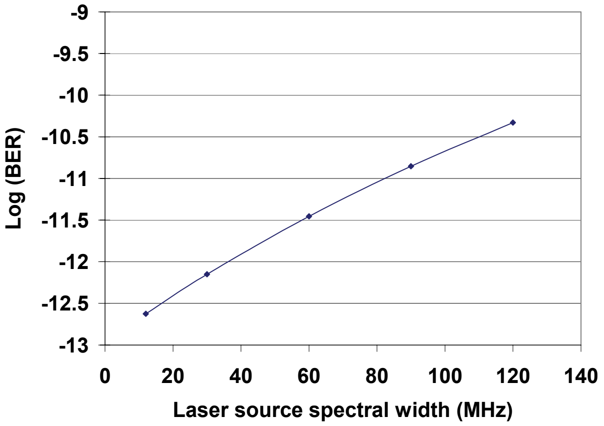


Fig. 5. Variation of BER with 10G-PON OLT laser source spectral width.

D. *Analysis of the Impact of Extinction Ratio*

Minimum extinction ratio value for the transmitting signal in the GPON system is 10 dB [4] while in the 10G-PON system a minimum allowed value is 8.2 dB [3]. Fig. 6 shows the influence of this parameter values on BER of the 10G-PON system.

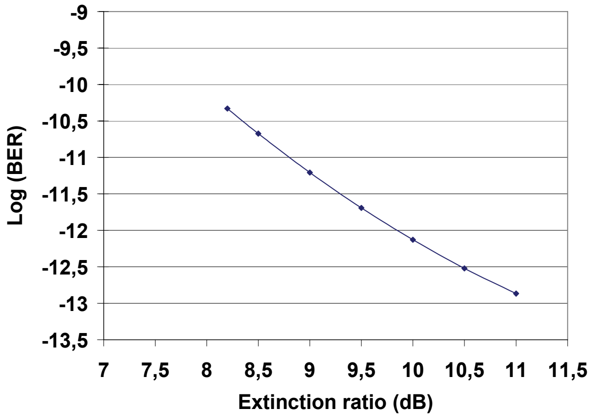
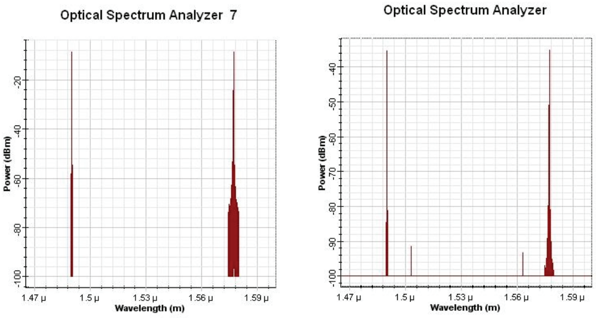


Fig. 6. Variation of BER with 10G-PON transmitted signal extinction ratio.

It is clear from the graphic that by changing the values of extinction ratio, "finer" adjustment of the system performances can be made. The influence of extinction ratio values on BER exists, but it is not too big.

E. Analysis of the Impact of WDM1 Multiplexer Parameters

The parameters of WDM1 filter whose influence on system performance was investigated in this analysis are its bandwidth (passband range) and signal suppression depth (channel isolation). The influence of filter's bandwidth is analyzed for the values from 10 - 30 nm, and signal suppression depth for values in the range of 30 - 50 dB. For these values, these two parameters didn't show any effect on the BER. It can be concluded that the cause to this was the fact that distance between the bands used for transmission of GPON and 10G-PON signals in the downstream direction (1490 nm and 1577 nm), is relatively large. This can be seen in Fig. 7 which depicts the optical spectrum of the transmitted signal at the start and at the end of ODN.



a.) b.)

Fig. 7. Optical signal spectrum for $P_{OLT\ GPON}$=5 dBm and $P_{OLT\ 10G\text{-}GPON}$=6 dBm: a) at the WDM1 output b) at the splitter output after transmission of 20 km.

The third and the most important parameter of WDM1 is the insertion loss of this element. It affects directly the system's loss margin, so naturally this parameter will have the greatest impact on the performance of the system.

F. Defining the Optimal values of 10G-PON Parameters

Analyses described in previous chapters provide information on how to choose the values of described parameters in order to provide performances needed for a specific system. The intensity of the impact of these parameters on the system is the most important information that was obtained from them. When choosing OLT and ONT for the 10G-PON system, their characteristics can be mutually complemented, depending on the differences in price, since each of them will have several different models/configurations available, with components that have different values of required parameters. This is very important, because in the evaluation of investment profitability, the difference in the cost of the OLT is shared among all users, and the difference in the cost of the ONT is multiplied by the number of users, which makes the ONT price much more sensitive to these differences.

However, taking into account that the aim of achieving the coexistence of existing GPON and new 10G-PON networks is to ensure gradual migration to these new systems, the replacement of user's GPON ONT with 10G-PON ONT in such networks will be performed when each of them desires it. So, in most cases, at the time of that replacement the new 10G-PON OLT will already be implemented in the network; exceptions exist only for users who migrate to the new system immediately upon achieved coexistence. Therefore, the selection of new 10G-PON ONTs will depend on the 10G-PON OLT that have already been used, i.e. their mutual "adaptation" will not be possible. On the basis of two extreme cases of possible OLT configuration, in a similar way as in section *A*, it is possible to determine the allowed values of ONT thermal noise.

Fig. 8 shows the range of allowed values of APD thermal noise depending on the configuration of the implemented 10G-PON OLT transmitter. Its two extreme configurations were examined: the optimal - with the OLT transmitter output power of 6 dBm, the laser source spectral width of 12 MHz and the extinction ratio of 10 dB and the minimum required - with the OLT transmitter output power of 2 dBm, the laser source spectral width of 120 MHz and the extinction ratio of 8.2 dB.

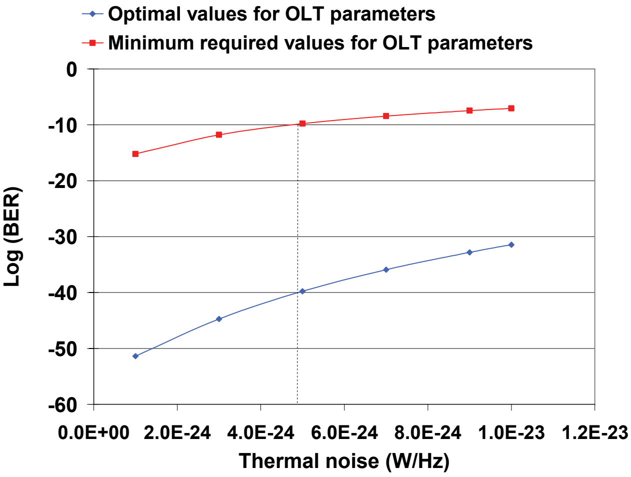


Fig. 8. Defining the maximum allowed values of 10G-PON ONT APD thermal noise.

It was observed that for the same value of ONT receiver thermal noise, a difference in BER values of up to 10^{37} can be achieved, depending on the configuration of OLT. Between the two curves, that correspond to the described extreme OLT configurations, are curves of all other possible OLT configurations, that comply with recommendations. As in the example with the two extreme cases, on the basis of the particular curve that belongs to any particular, implemented, 10G-PON OLT model, the maximum allowed APD thermal noise values may be analyzed. Thermal noise is a parameter that determines the sensitivity of the ONT receiver, and represents the most important characteristic of the receiver that directly affects its price and performance.

This analysis can be used for defining the allowed values of thermal noise and selecting them in accordance with a required performance. Its minimum required value can be determined in order to reduce the cost of the required ONT.

VI. CONCLUSION

There is plenty of room for technological improvement of the components of new network elements that are essential for future GPON networks and their coexistence with existing GPONs. Based on the results obtained by simulation of the coexistent system shown in this paper, the minimum values of the most important parameters of these components were defined (for the coexistence to be possible), as well as their recommended values for achieving the optimal performance of these systems. These values point to the required development path of those most important components.

REFERENCES

[1] ITU-T Recommendation G.987: „10-Gigabit-capable passive optical network (XG-PON) systems: Definitions, abbreviations, and acronyms“, 2010.

[2] ITU-T Recommendation G.987.1: „10-Gigabit-capable passive optical networks (XG-PON): General requirements “, 2010.

[3] ITU-T Recommendation G.987.2: „10-Gigabit-capable passive optical networks (XG-PON): Physical media dependent (PMD) layer specification“, 2010.

[4] ITU-T Recommendation G.984.2: „Gigabit-capable Passive Optical Networks (GPON): Physical Media Dependent (PMD) layer specification“, 2003.

[5] D. P. Shea, J. E. Mitchell, “A 10-Gb/s 1024-Way-Split 100-km Long-Reach Optical-Access Network,” *Journal of Lightwave Technology*, vol. 25, no 3, pp. 685-693, 2007.

[6] A. Vuković, K. Maamoun, H. Hua, and M. Savoie, “Performance Characterization of PON Technologies,” *Proceedings of the SPIE*, vol. 6796, pp. 67962W, 2007.

[7] OptiSystem software package, Optiwave, 2010. http://www.optiwave.com/products/system_overview.html